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(54) **Heat transfer tube**

(57) A heat transfer tube (10) for use in a heat exchanger where heat is transferred between a fluid flowing through the tube and a fluid flowing around the exterior of the tube and where the fluid external to the tube boils during the heat exchange process. The tube has at least one fin convolution (20) extending helically around its external surface (13). A pattern of notches (30) extends at an oblique angle (α) across the fin convolution at intervals about the circumference of the tube. There is a spike (22) between each pair of adjacent notches. The distal tip (23) is flattened. The maximum width (W_t) of the spike is greater than the width (W_r) of the proximal portion of the fin convolution and is of a width sufficient to overlap with the distal tips of spikes in adjacent fin convolutions, thus forming reentrant cavities between the adjacent fin convolutions and under the overlapping tips. The fin convolution, notches and spikes are formed in the tube by rolling the wall of the tube between a mandrel and, first, a gang of finning disks (63), then second, a notching wheel (66) and, third, a smooth wheel (67). Because, during the manufacture of the tube, of the interaction of the rotating and advancing tube, the notching wheel and the smooth wheel, the angle (β) of inclination of the axis of the tip of the spike is oblique with respect to the notch angle

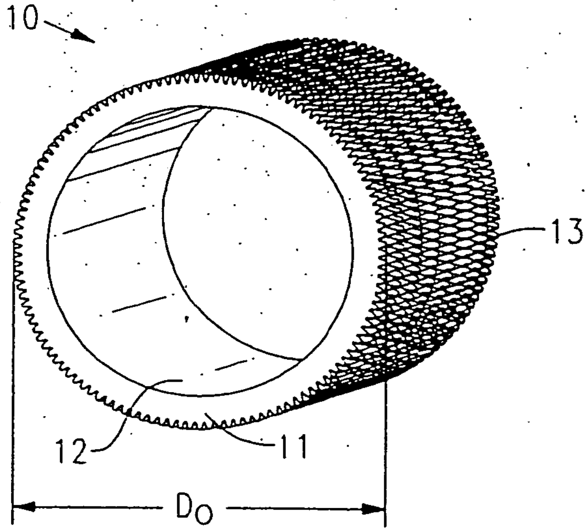

FIG.1

EP 0 713 072 A2

Description

BACKGROUND OF THE INVENTION

The present invention relates generally to heat transfer tubes. In particular, the invention relates to the external surface configuration of a heat exchanger tube that is used for evaporation of a liquid in which the tube is submerged.

Many types of air conditioning and refrigeration systems contain shell and tube type evaporators. A shell and tube evaporator is a heat exchanger in which a plurality of tubes are contained within a single shell. The tubes are customarily arranged to provide a multiplicity of parallel flow paths through the heat exchanger for a fluid to be cooled. The tube are immersed in a refrigerant that flows through the heat exchanger shell. The fluid is cooled by heat transfer through the walls of the tubes. The transferred heat vaporizes the refrigerant in contact with the exterior surface of the tubes. The heat transfer capability of such an evaporator is largely determined by the heat transfer characteristics of the individual tubes. The external configuration of an individual tube is important in establishing its overall heat transfer characteristics.

There are several generally known methods of improving the heat transfer performance of a heat transfer tube. Among these are (1) increasing the heat transfer area of the tube surface and (2) promoting nucleate boiling on the surface of the tube that is in contact with the boiling fluid. In the nucleate boiling process, heat transferred from the heated surface vaporizes liquid in contact with the surface and the vapor forms into bubbles. Heat from the surface superheats the vapor in a bubble and the bubble grows in size. When the bubble size is sufficient, surface tension is overcome and the bubble breaks free of the surface. As the bubble leaves the surface, liquid enters the volume vacated by the bubble and vapor remaining in the volume has a source of additional liquid to vaporize to form another bubble. The continual forming of bubbles at the surface, the release of the bubbles from the surface and the rewetting of the surface together with the convective effect of the vapor bubbles rising through and mixing the liquid result in an improved heat transfer rate for the heat transfer surface.

It is also well known that the nucleate boiling process can be enhanced by configuring the heat transfer surface so that it has nucleation sites that provide locations for the entrapment of vapor and promote the formation of vapor bubbles. Simply roughening a heat transfer surface, for example, will provide nucleation sites that can improve the heat transfer characteristics of the surface over a similar smooth surface.

In boiling liquid refrigerants, for example in the evaporator of an air conditioning or refrigeration system, nucleation sites of the re-entrant type produce stable bubble columns and good surface heat transfer characteristics. A re-entrant type nucleation site is a surface cavity in which the opening of the cavity is smaller than the subsurface volume of the cavity. An excessive influx of the surrounding liquid can flood a re-entrant type nudeation site and deactivate it. By configuring the heat transfer surface so that it has relatively larger communicating subsurface channels with relatively smaller openings to the surface, flooding of the vapor entrapment or nucleation sites can be reduced or prevented and the heat transfer performance of the surface improved.

SUMMARY OF THE INVENTION

The present invention is a heat transfer tube having one or more fin convolutions formed on its external surface. Notches extend at an oblique angle across the fin convolutions at intervals about the circumference of the tube. There is a fin spike between each adjacent pair of notches in a fin convolution. The distal tip of the a fin spike is flattened and wider than the fin root. The width of the tip is such that there is overlap between the tips of fin spikes in adjacent fin convolutions thus forming rentrant cavities between the fin convolutions.

The notches in the fin further increase the outer surface area of the tube as compared to a conventional finned tube. In addition, the configuration of the flattened fin spikes and the cavities formed by them promote nucleate boiling on the outer surface of the tube.

Manufacture of a notched fin tube can be easily and economically accomplished by adding an additional notching disk to the tool gang of a finning machine of the type that forms fins on the outer surface of a tube by rolling the tube wall between an internal mandrel and external finning disks.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings form a part of the specification. Throughout the drawings, like reference numbers identify like elements.

FIG. 1 is a pictorial view of the tube of the present invention.

FIG. 2 is a view illustrating how the tube of the present invention is manufactured.

FIG. 3 is a plan view of a portion of the external surface of the tube of the present invention.

FIG. 4 is a plan view of a portion a single fin convolution of the tube of the present invention.

a) there are and 13 to 28 fin convolutions per centimeter (33 to 62 fin convolutions per inch) of tube length, i.e. the fin pitch is 0.036 to 0.84 millimeter (0.014 to 0.033 inch), or

$$0.036 \text{ mm} \le P_f \le 0.84 \text{ mm } (0.014 \text{ inch} \le P_f \le 0.033 \text{ inch});$$

b) the ratio of fin height to tube outer diameter is between 0.02 and 0.05, or

$$0.02 \le H_f / D_o \le 0.05;$$

c) the density of notches in the fin convolution is 17 to 32 notches per centimeter (42 to 81 notches per inch);

d) the angle between the notch axis and the tube longitudinal axis is between 40 and 70 degrees, or

$$40° \le \alpha \le 70° \text{ and}$$

e) the notch depth is between 0.2 and 0.8 of the fin height or

$$0.2 \le D_n / H_f \le 0.8.$$

The optimum number of fin convolutions or fin "starts" depends more on considerations of ease of manufacture rather than the effect of the number on heat transfer performance. A higher number of starts increases the rate at which the fin convolutions can be formed on the tube surface but increases the stress on the finning tools.

Claims

1. An improved heat transfer tube (10) in which the improvement comprises:

at least one external fin convolution (20) disposed helically about of said tube;
notches (30) extending radially into said fin convolution at intervals about the circumference of said tube;
each of said notches having a base axis that is at an oblique angle (α) with respect to the longitudinal axis (A_T) of said tube;
said notches dividing said fin convolution into a proximal portion (21) and a spike portion (22) having a single flattened distal tip (23),
said spike portion being between a pair of adjacent said notches and having a maximum width (W_t) that is both greater than the maximum width (W_r) of said proximal portion and sufficient so that said spike overlaps with spikes in both adjacent fin convolutions and
a distal tip axis (β) that is oblique to said notch base axis.

2. The tube of claim 1 in which:

there are 13 to 28 fin convolutions per centimeter (33 to 70 fin convolutions per inch) of tube;
the ratio (H_f / D_o) of the height of said fin convolution (H_f) to the outer diameter of said tube (D_o) is between 0.02 and 0.05;
the density of said notches in said fin convolution is 17 to 32 notches per centimeter (42 to 81 notches per inch);
the angle between said notch base axis and said tube longitudinal axis is between 40 and 70 degrees; and
the depth of said notches is between 0.2 and 0.8 of said fin convolution height.

3. A heat transfer tube (10) comprising:

a tube wall (11) having an outer surface(13);
at least one fin convolution (20) formed by the interaction of a finning disk (63) and a mandrel (64), extending from said tube outer surface;
notches (30), formed by a notching wheel (66), extending radially into said fin convolution at intervals about the circumference of said tube, and dividing said fin convolution into a proximal portion and a spike portion (22),
each of said notches having a base axis that is at an oblique angle (α) with respect to the longitudinal axis (A_T) of said tube; and
said spike portion (22) having a flattened distal tip (23), formed by said notching wheel and a smooth wheel (67), between a pair of adjacent said notches, that overlaps with similar distal tips in both adjacent fin convolutions,
said distal tip being between a pair of adjacent said notches and having a maximum width (W_t) that is greater than the maximum width (W_r) of said proximal portion and a distal tip axis (β) that is oblique to said notch base axis.

FIG. 5 is a generic sectioned elevation view of a single fin convolution of the tube of the present invention.

FIGS. 5A, 5B, 5C and **5D** are sectioned elevation views, through, respectively, lines **5A-5A, 5B-5B, 5C-5C** and **5D-5D** in **FIG. 4**, of a single fin convolution of the tube of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 is a pictorial view of heat transfer tube **10**. Tube **10** comprises tube wall **11**, tube inner surface **12** and tube outer surface **13**. Extending from the outer surface of tube wall **11** are external fins **22**. Tube **10** has outer diameter D_o, including the height of fins **22**.

The tube of the present invention may be readily manufactured by a rolling process. **FIG. 2** illustrates such a process. In **FIG. 2**, finning machine **60** is operating on tube **10**, made of a malleable metal such as copper, to produce both interior ribs and exterior fins on the tube. Finning machine **60** has one or more tool arbors **61**, each containing tool gang **62**, comprised of a number of finning disks **63**, notching wheel **66** and smooth wheel **67**. Extending in to the tube is mandrel shaft **65** to which is attached mandrel **64**.

Wall **11** is pressed between mandrel **64** and finning disks **63** as tube **10** rotates. Under pressure, metal flows into the grooves between the finning disks and forms a ridge or fin on the exterior surface of the tube. As it rotates, tube **10** advances between mandrel **64** and tool gang **62** (from left to right in **FIG. 2**) resulting in a number of helical fin convolutions being formed on the tube, the number being a function of the number of tool arbors **61** in use on finning machine **60**. In the same pass and after tool gang **62** forms fins on tube **10**, notching wheel **66** impresses oblique notches into the fins then smooth wheel **67** flattens and spreads the distal tips of the fins.

Mandrel **64** may be configured in such a way, as shown in **FIG. 2**, that it will impress some type of pattern into the internal surface of the wall of the tube passing over it. A typical pattern is of one or more helical rib convolutions. Such a pattern can improve the efficiency of the heat transfer between the fluid flowing through the tube and the tube wall.

FIG. 3 shows, in plan view, a portion of the external surface of the tube. Extending from outer surface **13** of tube **10** are a number of fin convolutions **20**. Extending obliquely across each fin convolution at intervals are a pattern of notches **30**. Between each pair of adjacent notches in a given fin convolution is a fin spike **(22)** having a distal tip **23**. The fin pitch, or distance between adjacent fin convolutions, is P_f.

FIG. 4 is a plan view of a portion of a single fin convolution of the tube of the present invention. The angle of inclination of notch base **31** from longitudinal axis of the tube A_T is angle α. The angle of inclination of fin distal tip **23** from longitudinal axis of the tube A_T is angle β. Because, during manufacture of the tube *(see* **FIG. 2**), of the interaction between rotating and advancing tube **10**, notching wheel **66** and smooth wheel **67**, the axis of spike **22** is turned slightly from the angle between the teeth of the notching wheel and the fin convolution so that tip axis angle β is oblique with respect to angle α, i.e., $\beta \neq \alpha$.

FIG. 5 is a pseudo sectioned elevation view of a single fin convolution of the tube of the present invention. We use the term pseudo because it is unlikely that a section taken through any part of the fin convolution would look exactly as the section depicted in **FIG. 5**. The figure, however, serves to illustrate many of the features of the tube. Fin convolution **20** extends outward from tube wall **11**. Fin convolution **20** has proximal portion **21** and spike **22**. Extending through the fin at the pseudo section illustrated in a notch having notch base **32**. The overall height of fin convolution **20** is H_f. The width of proximal portion **21** is W_r and the width of spike **22** at its widest dimension is W_t. The outer extremity of spike **22** is distal tip **23**. The distance that the notch penetrates into the fin convolution or notch depth is D_n. Notching wheel **66 (FIG. 2)** does not cut notches out of the fin convolutions during the manufacturing process but rather impresses notches into the fin convolutions. The excess material from the notched portion of the fin convolution moves both into the region between adjacent notches and outwardly from the sides of the fin convolution as well as toward tube wall 11 on the sides of the fin convolution . As a result, W_t is significantly greater than W_r and is sufficient so that the distal tips of spikes in adjacent fin convolutions overlap one another so that reentrant cavities are formed between adjacent fin convolutions and under the overlapping distal tips.

FIGS. 5A, 5B, 5C and **5D** are sectioned elevation views of fin convolution 20 respectively taken at lines **5A-5A, 5B-5B, 5C-5C** and **5D-5D** in **FIG. 4**. The views show more accurately the configuration of notched fin convolution 20 at various points as compared to the pseudo view of **FIG. 5**. The features of the notched fin convolution discussed above in connection with **FIG. 5** apply equally to the illustrations in **FIGS. 5A, 5B, 5C** and **5D**.

We have tested a prototype tube made according to the teaching of the present invention. That tube has a nominal outer diameter (D_o) of 1.9 centimeters (3/4 inch), a fin height of 0.61 millimeters (0.0241 inches), a fin density of 22 fin convolutions per centimeter (56 fin convolutions per inch) of tube length, 122 notches per circumferential fin convolution, the axis of the notches being at an angle of inclination (α) from the tube longitudinal axis (A_T) of 45 degrees and a notch depth of 0.20 millimeter (0.008 inch). The tested tube has three fin convolutions, or, as is the term in the art, three "starts."

Extrapolations from test data indicate that the external surface configuration of the tube of the present is suitable for tubes having nominal outer diameters of from 12.5 millimeter (1/2 inch) to 25 millimeter (1 inch) where:

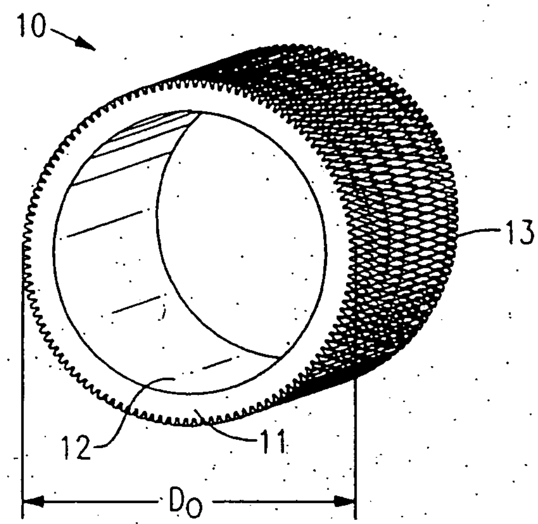

FIG.1

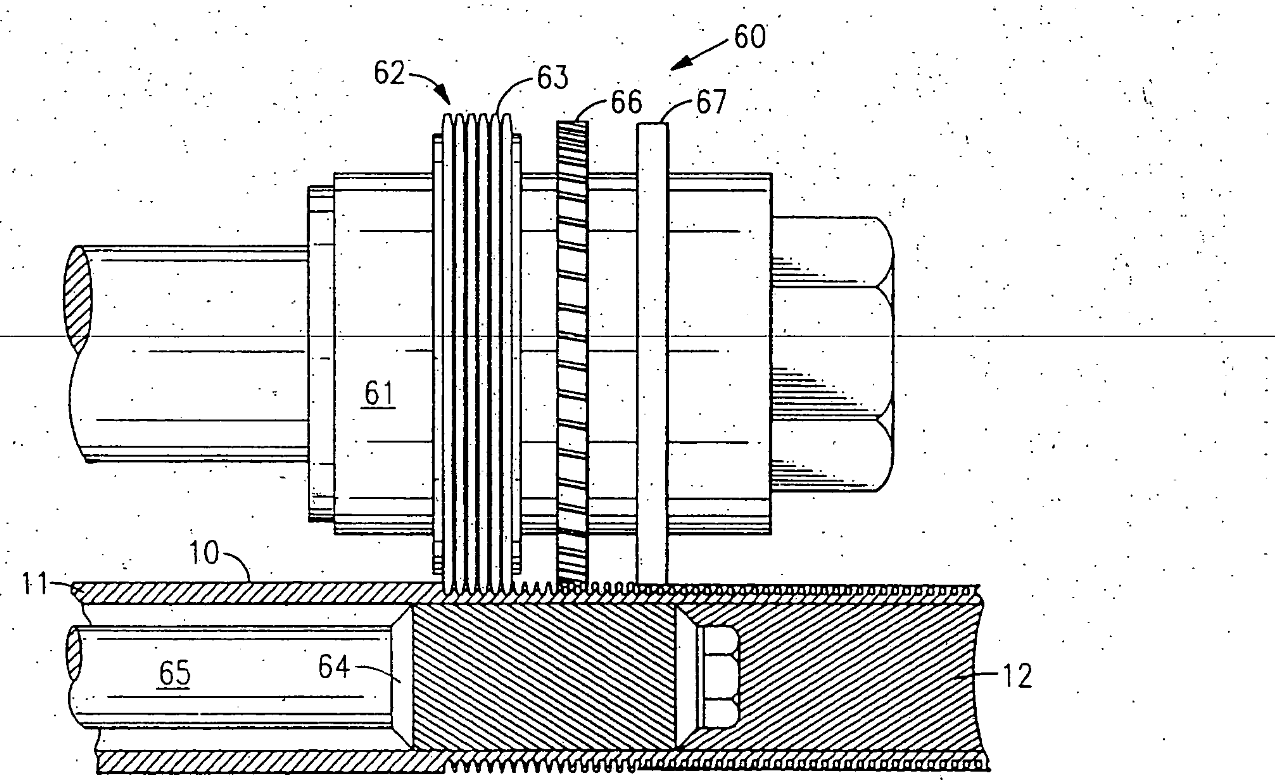

FIG.2

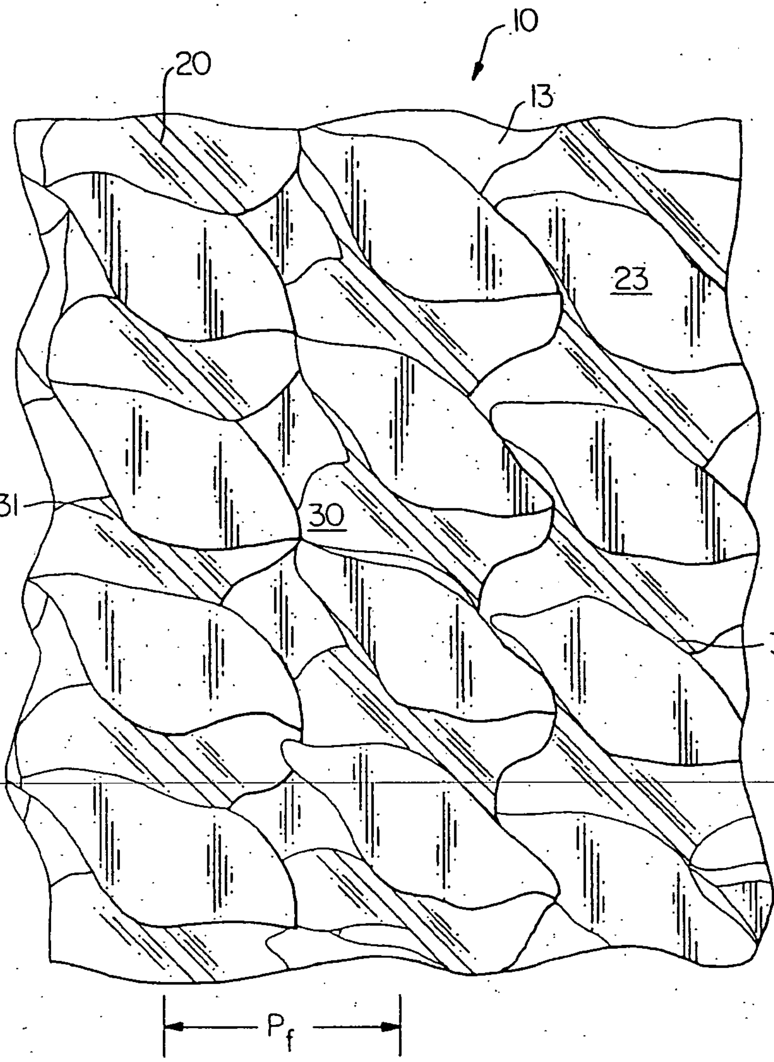

FIG. 3

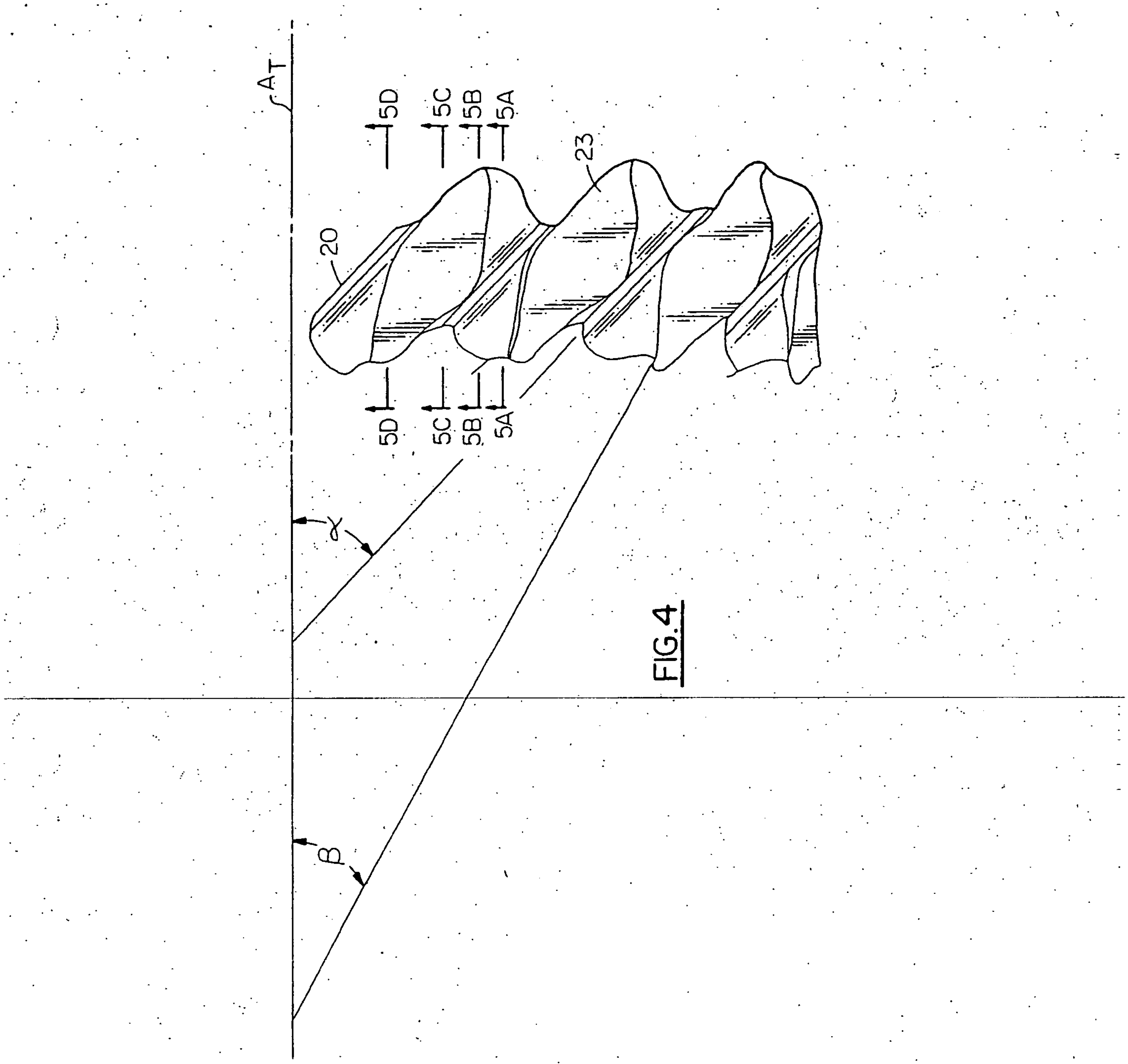

FIG.4

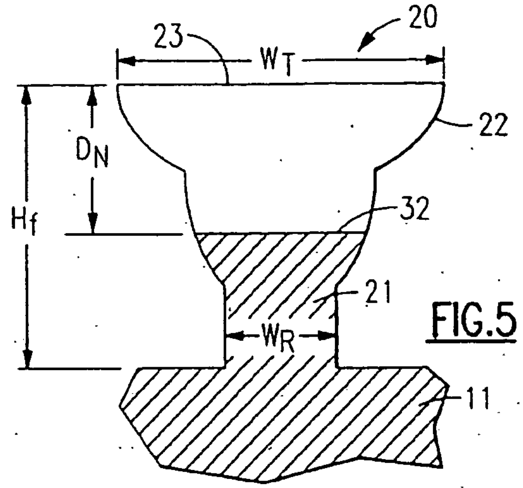

FIG.5

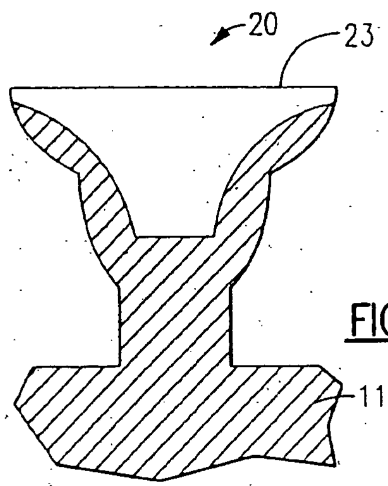

FIG.5A

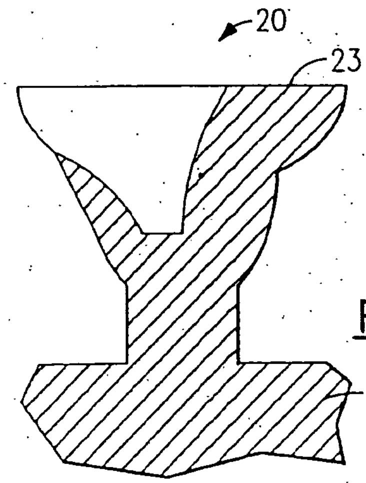

FIG.5B

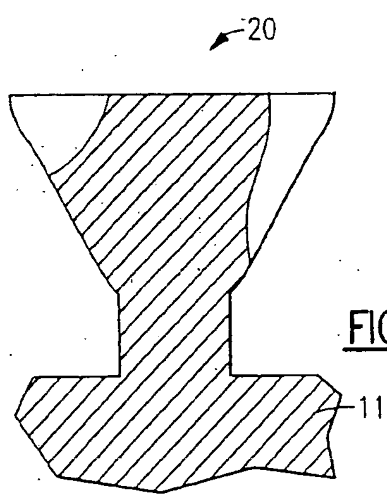

FIG.5C

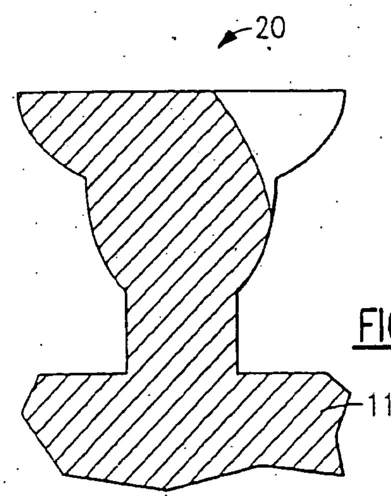

FIG.5D